A Study on Thermal and Acoustic Characteristics of Bagasse Fibre Reinforced epoxy composites

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

Master of Technology

In

Mechanical Engineering

(Specialization: Thermal Engineering)

By

AAKASH KOLI
(Roll No. 213ME3434)

Department of Mechanical Engineering
National Institute of Technology
Rourkela, Odisha (India)

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AAKASH KOLI
(Roll No. 213ME3434)

Under the supervision of

Prof. Alok Satapathy

Department of Mechanical Engineering
National Institute of Technology
Rourkela, Odisha (India)

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CERTIFICATE

This is to certify that the thesis entitled "***A Study on Thermal and Acoustic Characteristics of Bagasse Fibre Reinforced epoxy composites"***, submitted by **Aakash koli** (Roll No: 213ME3434) has been carried out under my supervision in partial fulfilment of the requirements for the degree of ***Master of Technology*** in ***Mechanical Engineering (Specialization: Thermal Engineering)*** during session 2014 - 2015 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

Place: Rourkela

Date:

Prof. Alok Satapathy
Assistant Professor
Department of Mechanical Engineering
National Institute of Technology, Rourkela
Odisha, India

A C K N O W L E D G E M E N T

I would like to express my deep sense of gratitude and respect to my supervisor

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Place: Rourkela

Date:

Aakash koli

Roll No. 213ME3434

Department of Mechanical Engineering

National Institute of Technology, Rourkela

Odisha, India

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This research work mainly deals with processing and characterisation of bagasse fiber reinforced epoxy composite. Effective Thermal conductivity and sound absorption coefficient of bagasse fiber reinforced epoxy composites are analysed experimentally by consuming the bagasse fiber from sugarcane waste stock in fabricating the sound absorber material by simple hand layup technique. In the first part their acoustic properties such as sound absorption coefficient (α) are examined and compared with experimental values. In second part the results are compared with the effective thermal conductivity (K_{eff}) values obtained from experiment by using the established models such as Rule-of-Mixture (ROM), Maxwell's model, bruggeman equation, Lewis and Nielsen. The thermal conductivity values are measured with the UnithermTM model 2022 tester according to the ASTM standard E-1530 whereas, absorption coefficient values are measured in impedance tube machine. According to the research analysis the reinforcement of the bagasse fiber results in reduction of thermal conductivity of epoxy as well as increased in the sound absorption coefficient on increment of filler volume fraction. With up gradation in heat insulation and sound absorption capacity, these reinforced epoxy composites can discover their application in wall insulation, food container, thermos- flask and other similar thermal and acoustic insulation applications.

Key Words*: Acoustic absorption coefficient (α), bagasse fiber, effective thermal conductivity coefficient (K_{eff})*

Contents

Chapter - 1

INTRODUCTION

1.1 Background and Inspiration

1.1.1 Requirement of Thermal Insulation

The purpose of thermal insulation mainly in building and household construction is to maintain a cool, comfortable hygienic climatic condition in the case of high ambient temperature or to maintain the warmth in case of low ambient temperature condition by retarding the flow of heat with the help of insulation medium. Insulation has also several applications in industry like it prevents the damages caused due to freezing or damage of articles by high temperatures, results in lowering the cost for heating and cooling. Heat flows spontaneously from high temperature body to a low temperature body unidirectional that is where insulation helps in slowing down this heat flow.

It is observable that maximum work is concentrated in the area of improving the thermal conductivity of polymer reinforced composites rather than improving the thermal insulation capacity. Thermal insulation has a huge application in refrigeration and air conditioning, building insulation, thermo-flasks, food preservation industries, aerospace and automotive industries and many mores.

1.1.2 Requirement of acoustic insulation

Sound insulation is the prevention of sound energy or waves being transmitting from one side of building wall to another. In this fast growing modern world expanding application of electrical, electronic and mechanical devices at home and commercial enterprises, industries has focused the problem for sound pollution generated by them. Transformation and heavy growth of manufacture work going in every immediate nearby further increases the need of latest technologies for sound reduction. There are mainly two ways for blocking the noise produced by different machines in environment which is either by suppressing the resource and other factors producing the noise or by using the sound proofing materials which will block or absorb the acoustic wave energy. Traditionally, for controlling the noise different costly and synthetic sound absorbing materials were used such as glass fiber, carbon fiber and polymer fibres which poses an extra threat to living organism and environment. For such major issues a substitute, natural fibres such as bagasse, jute, paddy, cotton, flax, ramie, sisal, and hemp and many more harnessed from renewable resource can be used as a sound absorbing materials which is cheap, biodegradable and recyclable and abundantly available. Although now a days there natural fiber reinforced composites are exclusively being used for various applications in automotive industry, construction, building sectors, furniture etc. By using these natural fiber materials risk of physical harm and health factors, has also minimizes a lot. At presently the main concern of different researchers and scientists, is to develop an economical low cost, renewable and biodegradable sound absorbing material with the non-abrasive, light weight, good thermal insulator, hygroscopic and combustible material for automotive industries, house hold appliances and structural applications.

For high strength application and structural application many synthetic fibers like glass, nylon, carbon fiber etc. are considered to be an important reinforced material. Some of them are Glass fiber reinforced polymer composites which are heavily used, mainly due to their low density and excellent specific stiffness and strength and low thermal conductivity. However these synthetic fiber have some disadvantages like they are corrosive and toxic in nature, costly, non-renewable, and non-combustible in nature which poses serious environmental harm and need to be considered.

Therefore natural fibers such as sisal, jute, sugarcane, coconut coir, rice husk, banana etc., are easily available but are not fully utilized. At present, these common filaments are utilized as a part of the generation of mats, ropes, and yarns and tangling and additionally underway of extravagant articles like place settings, satchels, tapestry and handbags. Cotton, banana and pineapple are additionally utilized as a part of making fabric not withstanding being utilized as a part of the paper business. With developing ecological responsiveness and natural concern, consideration towards regular fiber fortified composites have expanded amid the late decades. The composites have numerous favourable circumstances, including minimal effort, light weight, nontoxic, and biodegradable and so on. Different regular fillers like pineapple, sisal and bamboo, coconut coir, jute and so on as the fortifications in composites have been accounted for before. Aside from this, regular filaments have low warm conductivity which is much lower than engineered fiber and can be utilized as filler for different protection applications.

In this manner, there has been a centre to manufacture a sort of light, permeable material with better mechanical quality and great thermal protection properties. Against this setting, developed a class of promising designing protection material– polymer composite

1.2 Composite Materials

When two or more chemically as well as physically different materials combined together, it results in improved properties over the individual materials. There are natural and synthetic composites. Wood is a very old example of a natural composite, which is a combination of cellulose fiber and lignin. The cellulose fiber gives it strength and the lignin act as “glue" which hold the fibres and provide stability. Composite material consist of mainly two phases, one is called as matrix material and another is reinforcing material. Matrix material in which reinforcing material is embedded. The matrix material is continuous phase and reinforcing is discontinuous phase. The reinforcing phase has greater strength than the matrix phase. Matrix phase relief the residual stresses generated during reinforcing and also protect the composite from physical and environmental damage. The function of reinforcing material is to provide strength and having low density whereas matrix phase is usually ductile and tough. Composite are the combination of two or more than two different material. The reinforcement can be used as in powder form, fibers, particles, whiskers or lamellae, which are then embedded in a suitable matrix according to the application, thereby enhancing the overall properties of the composite material. In early 1940's, glass fiber reinforced plastic were came into picture which are having high structural strength and ultralow weight. Since then technology of reinforced polymers has significantly increased. In a typical glass fiber reinforced plastic composite, glass fibre provide the strength and elasticity whereas thermal capabilities are provided by the plastic matrix. These composites are then regressively used in air craft, automobile industry.

1.2.1 Matrix material

Now a day's polymer, metal, ceramic, thermosets and thermoplastics are widely used matrix materials which have been used for making composites. The matrix material should be tough and ductile in nature for serving the proper function of composite material. Accordingly different type of reinforcement are being used such as dispersions, particulates, bristle, discontinuous or continuous fibers. The matrix phase provide strength to the composite to resist compressive, tensile, shear or fatigue loads. Thermosetting or thermoplastic resins are used as polymers in matrix material of composites. Thermoset resins are the polymers which once gets into shape, can't be reshaped or remoulded. Some of them are mostly use in making composites such as epoxy, polyester, phenolic, vinyl ester, polyurethane, silicone, polyamide and polyamide-imide. Thermoplastic resins are the polymer compound which soften on heating and returns to its original solid state on cooling. Thermoplastic resins are the polymer compound which soften on heating and returns to its original solid state on cooling. Commonly used thermoplastic resins are PET, PVC, polyethylene, poly carbonate, vinyl, polypropylene, nylon.

Here epoxy resin which is a kind of thermosetting polymer is used in developing the composite. Epoxy resin are cured by adding curing agent called hardener in 10:1, 10 part of epoxy resin and 1 part of hardener to perform efficiently at elevated temperature, having excellent mechanical properties, hydrophobic in nature and high glass transition temperature. It is important to take proper ratio of epoxy and hardener so as to take maximum benefits of the properties. Fiber reinforced composites are becoming very popular in manufacturing sector which is a key of enhancing the properties of the material. It is used in developing the high performance products that requires high strength as well as lightweight finding major application in automobile, aerospace, sports, medical instruments, household, industries and many more.

1.2.2 Reinforcement

The role of reinforcement is to enhance the overall mechanical properties such as strength, stiffness and failure resistance of the system. They are in form of whiskers, fibers, lamellae or a mesh. Reinforcement can be used to either conduct or insulate heat and electricity. The selection of reinforcement is very important for the properties that are needed for specific application. Orientation of reinforcement also plays the important role for achieving the required properties. Frequently used reinforcement are metallic whiskers, carbon, ceramic, natural, glass, metallic, oxides, carbides and nitrides.

1.2.3 Types of Composite Materials

Classification on the basis of matrix material:

- Metal Matrix Composites
- Ceramic Matrix Composites

- Polymer Matrix Composites

Metal matrix composites:

Metal matrix composite have shown remarkable development in using the required properties of metals and their alloys as comparing to the old methods of alloying and heat treatment. These composites are capable enough of achieving the properties which are impossible in single alloys. These matrix can be continuous or discontinuous reinforcement composed of may be particles, fibers or whiskers. Powder metallurgy or melting metal are the two process by which ceramic particles are embedded in the metal matrix which improve the strength, wear resistance, thermal resistance and coefficient of thermal expansion

Ceramic matrix composites:

Ceramics matrix are extensively used because of its several properties like lighter, harder, corrosion resistance and high hot hardness, therefore these composites can withstand higher temperature than any other composites. Oxides, carbides, nitrides, borides, glasses and silicates are the most commonly used ceramic matrices and reinforcements used are SiC, $Si_3 N_4$, $Al_2 O_3$, BN, ZrO_2, AIN and C in the form of fibers, whiskers or particulates. These composites are produced by experiencing distinctive procedures like sintering, hot squeezing, hot isostatic squeezing, penetration, compound holding and ignition. At present the real use of artistic framework composites are in making additions of cutting device, wear safe composites, space transport tiles and aviation parts. Other potential application incorporates motor parts, protection of military vehicles, and driving edge application in aviation and high temperature consumption safe parts. Other potential application incorporates bio-Earthenware and high temperature ceramic super conduit composite wires for force transmission links, engines and super leading attractive vitality stockpiling framework.

Polymer matrix composites:

Polymer matrix are highly preferable matrix material than any other matrix materials. Polymer when reinforced with fillers it enhance the strength, thermal strength and stiffness to much extent. Based on the fillers material used in polymer matrix, it can varies the conductivity or insulating properties of the composite. The reason of popularity of polymer composite is its easy fabrication technique which incurred less cost than any other matrix and doesn’t require highly operated technician. Polymer composites are mostly used because it has superior overall properties than any other individual polymer. These composites can be easily fabricated without applying high pressure, temperature and energy due to its high ductility or high modulus of elasticity.

1.2.4 Types of polymer composites

Broadly, polymer composites can be classified into two groups on the basis of reinforcing material. They are:

- Fiber reinforced polymer
- Particle reinforced polymer

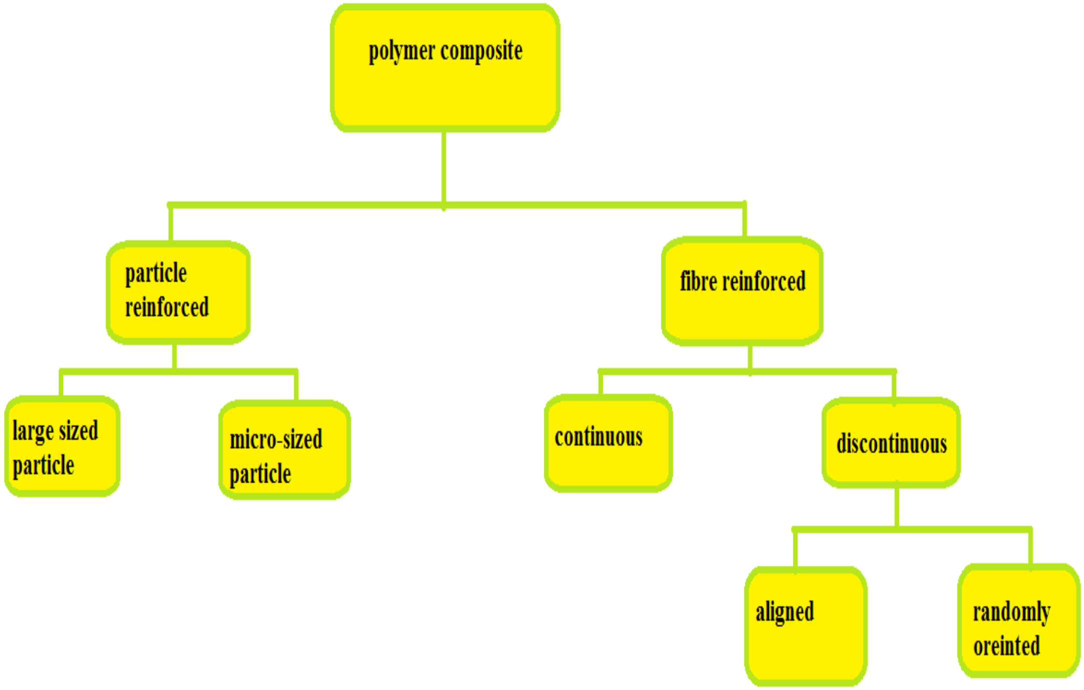

Fig.1.1 Classification of composites based on reinforcement type

Fiber reinforced polymer

Fibres when reinforced or embedded with polymer matrix it results in composite which is much stronger than single component. Glass, carbon, molybdenum, beryllium, beryllium carbide, beryllium oxide and natural fibre such as bagasse, jute, banana, paper, wood or asbestos are commonly used fibre reinforcement. The Fibre reinforced polymer composites covers large area of applications including the aerospace, automobile, marines, and construction industries. Fibers reinforcement are the principle cause of strength while matrix binds all the fibers together in proper shape and distributes stresses among the reinforcing fibers. The fibers transmit the loads lengthwise. In some cases fillers may be added to ease the fabrication process so as to cut the cost of manufacturing. Common matrix materials used now a days are epoxy, phenolic resin, polyester, polyurethane, vinyl ester etc. Among all these matrix materials, epoxy is generally used because of its higher adherence and less contraction than polyesters.

Particle reinforced polymer

Particulate composites have an added substance constituent which is basically maybe a couple dimensionally and naturally visible/minuscule. In a few composites on the other hand, the added substance constituent is visibly non-dimensionally, i.e., theoretically a point, instead of a line or a zone. Just on the minuscule scales does it get to be dimensional, i.e., a molecule, and hence the idea of composite must come down to the tiny level in the event that it is to include all the composite of enthusiasm of architects. Particulate composites vary from the fiber chip sorts in that conveyance of the added substance constituent is typically irregular instead of controlled. Particulate composite are hence typically isotropic. This group of composites incorporates scattering solidified compound and cermet. Just on the minute scales does it get to be dimensional, i.e., a molecule, and accordingly the idea of composite must come down to the tiny level in the event that it is to incorporate all the composite of enthusiasm of designers. Particulate composites vary from the fiber chip sorts in that dissemination of the added substance constituent is generally irregular as opposed to controlled. Particulate composite are hence normally isotropic. This group of composites incorporates scattering solidified amalgam and cermet.

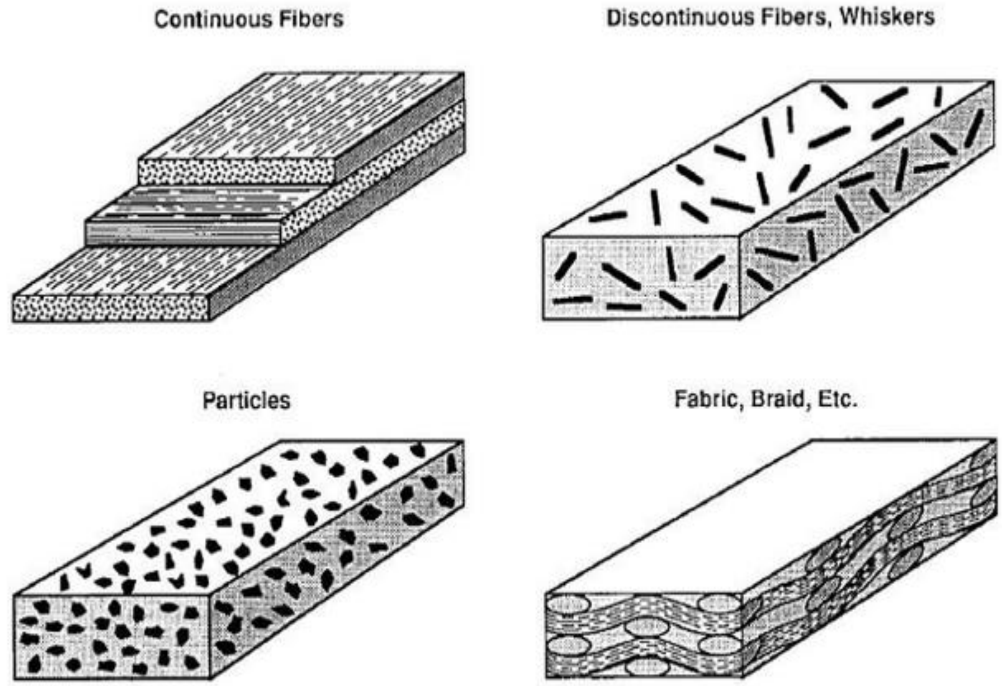

Fig.1.2. Types of reinforcement

1.3 Objective of research work

The present work is actually an analytical and experimental investigation concentrated on thermal as well as acoustic characteristics of natural fibre (bagasse fibre) reinforced epoxy composites.

- To develop a class of low cost thermally and acoustically insulated polymer composites using bagasse fibre reinforcement in epoxy resin.
- To determine effective thermal conductivity experimentally and study the effect of fibre volume fraction.
- To determine the acoustic absorption coefficient experimentally and to study the role of fibre.
- To explore possible application areas for these newly developed composites.

The main aim of insulating here is to retard the heat flow and maintain the low temperature. It is basically used as a thermal barrier for the devices and instruments which are need to be maintained at specific temperature without any thermal damage. Taking under consideration, the present work has been adopted to study the effect of adding insulated short fibers of sugarcane waste reinforced epoxy composite. The main objective of the present work includes fabrication of a new class of low cost composites in which short bagasse fibers are used as reinforcement to improve the insulating capabilities of epoxy resin. k_{eff} is calculated using existing mathematical model using the conductivity of fibre and epoxy. Based on these model, a correlation between the effective thermal conductivity of the composite and the fiber content is proposed. Short bagasse fiber are used as a fillers in present work reinforced individually in epoxy resin to fabricate four sets of composites by simple hand lay-up technique. The proposed model is then validated through experimentation conducted in controlled laboratory conditions. The k_{eff} of all the fabricated composites with different compositions are numerically evaluated using finite element method and the results are validated through measured values. The comparison of k_{eff} values obtained from incorporation of two different fibers is also reported in present work.

1.4 Thesis outline

The remainder of this thesis is organized as follows:

Chapter 2: Comprises a literature review or the work which has been already done on natural fibres composites. It emphasis on their acoustic properties and thermal conductivity.

Chapter 3: Comprises an explanation of the raw materials and the experiment procedures. It also includes the details of fabrication and characterization of the composites under investigation.

Chapter 4: Presents the results of mathematical model and experimental investigation on the thermal conductivity and acoustic behaviour of the composites under research.

Chapter 5: Conclusions drawn from both the experimental and analytical efforts and recommends ideas and directions for future research.

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Chapter - 2

LITERATURE REVIEW

In this chapter, an overview of the survey made on past research which has already available has been presented. The main objective of this literature survey is to present the past research on fibre reinforced polymer composites. It include the work on thermal behaviour as well as acoustic characteristics of the fibre filler reinforced polymer composites and thereby calculating the performance of the polymer composite. It include the following available research domain:

2.1 Research work on synthetic fiber reinforced polymer composites

A remarkable work was finished by numerous specialists on engineered fiber strengthened polymer composites. Marom et al. [1] focused on the flexible properties of engineered fiber-strengthened polymer composite materials that relate to biomedical applications and exhibits the scope of solidness realistic through choice of constituents and by decision of edge of fortification. Vijay et al. [2] conveyed an inside and out examination and complete learning to the novices in the field of regular cellulose strands/polymer composites. The primary point of this audit article is to uncover the present improvement and developing uses of normal cellulose strands and their polymer materials. Yongli [3] considered the mechanical practices of unidirectional flax and glass fiber strengthened cross breed composites with the point of examination on the mixture impacts of the composites made by normal and manufactured filaments. Cho et al. [4] examined the mechanical conduct of carbon fiber/epoxy composites and acquired that the composites fortified with nanoparticles enhanced mechanical Properties, for example, upgraded compressive quality and enplane shear properties. Chauhan et al.[5] contemplated on the impact of fiber stacking on mechanical properties, rubbing and wear conduct of vinyl ester composites under dry and water greased up conditions and reported that the thickness of composite examples is influenced barely by expanding the fiber content. Huang et al. [6] contemplated on impact of water retention on the mechanical properties of glass/polyester composites. It was built up that the breaking quality and malleable anxiety of the composites diminished progressively with expanded water inundation time on the grounds that the debilitating of holding in the middle of fiber and framework.

2.3. Thermal Conductivity of Polymer Matrix Composites

Impressive work has been accounted for in accessible writing on the warmth transport in polymers by Hennig and Knappe [7], Hanson and Hoe [8], Penge and Landol [9], Choy and Young [10] and so on. Later on, Tavman [11] effectively gave a standard to anisotropic warmth conduction conduct of polymers by changing their sub-atomic introduction. In a late work Griesinger et al. [12] have reported that the warm conductivity of polyethylene increments from 0.35 to 50 W/m-K by keeping an introduction proportion of 50. Then again, the majority of the studies are kept to the warm conduct of flawless polymer and not to their composites.

Since it is not generally conceivable to manufacture a composite keeping the sub-atomic introduction according to decision, a more functional technique to build the warm conductivity of the polymer is by including thermally conductive particles or strands onto it. Part of work has been accounted for to enhance the warm conductivity of polymers by consolidating conductive fillers. A large portion of them incorporate test determination of compelling warm conductivity of particulate filled polymer composites

Metals are known for their high warm conductivity, so they are in effect generally utilized as fillers as a part of polymer composites. Sofian et al. [13] contemplated the impact of different metal powders like copper, zinc, iron and bronze on the warm properties like conductivity, diffusivity and particular warmth of high-thickness polyethylene network. Mamunya et al. [14] later reported the change in warm conductivity of two distinct classifications of polymers i.e. thermoplastic (polyvinyl chloride) and thermoset (epoxy) loaded with copper and nickel particles. In spite of the fact that in 1990s, Tecke et al. [15] and Tavman [16] had effectively utilized copper powder as filler and measured the warm conductivity of the composites by hot circle strategy, all the more as of late copper has again been utilized by Luyt et al. [17] in low thickness polyethylene. They have reported around 150% expansion in the estimation of warm conductivity for the composites loaded with 24 vol% of copper. Thusly, Tavman [18] took aluminum powders as filler and mulled over the warm property of high thickness polyethylene though later Boudenne et al. [19] gave an outline on the warm conductivity of polypropylene/aluminum composites. Silver too has a high potential to be utilized as filler as a result of its high warm conductivity. The impact of silver particulates in epoxy was mulled over by Bjorneklett et al. [20]. Albeit filling of a polymer with metallic particles brought about expanded warm conductivity; synchronous increment in thickness of the composites was likewise recorded, consequently confining the utilization of metal powders for light-weight applications.

Carbon-based fillers with high warm conductivity and low thickness seem, by all accounts, to be the most encouraging fillers for enhancing warm conductivities of polymer composite. Graphite, carbon fiber and carbon dark are no doubt understood carbon-based fillers. Graphite is considered as the best conductive filler in view of its great warm conductivity and ease [21]. Graphite with single graphene sheet indicates naturally high warm conductivity of around 800W/m-K [22]. Extended graphite, a peeled type of graphite with layers of 20-100nm thickness, has additionally been utilized as a part of polymer composites [23]. It was found that warm conductivity of the artificially functionalized graphite/epoxy composite with such peeled graphite (20wt %) expanded from 0.2 to 5.8 W/m-K. Carbon fiber, commonly vapor developed carbon fiber (VGCF), is an imperative carbon-based filler [24]. Studies directed on adjusted warm conductivity of polymer composites loaded with carbon nanotubes have as of late been investigated by Han and Fina [25]. Metallic and carbon-based fillers are very conductive thermally, yet they are exceedingly electrically conductive too. There are sure territories where high warm conductivity is obliged yet in the meantime electrical resistivity is of prime significance, similar to in electronic gadgets. All things considered an offset is obliged that amplifies the warm scattering impact of the electrically protecting embellishment compound and which keeps the spillage of current over the channels because of low resistivity. Artistic powder fortified polymer materials are being utilized broadly for smaller scale electronic applications in light of their high warm and low electrical conductivity. It is seen from the above writing on earthenware molecule filled polymers that there is an obvious increment in warm conductivity of the composite with expansion in filler focus though no noteworthy changes are seen in electrical conductivity of such composites. Consolidation of various fillers into the polymer lattice for the change of warm conductivity has additionally been accounted for [26- 27]. Components other than the inborn warm conductivity of the fillers, for example, shape, size, circulation and interconnectivity between the particles additionally choose the composite warm conductivity. Boudenne et al. [28] concentrated on the impact of two distinctive molecule sizes of aluminum filler and found that the composite loaded with bigger molecule size shows fundamentally high warm conductivity. It is because of the development of more steady thermally conductive pathways in the framework material. Comparable conduct was seen by Zhou et al. [29]. Despite what might be expected, a few writers have highlighted the higher warmth transport capacity of the composites loaded with littler particles [30, 31]. Boudenne et al. [32] excessively explored different avenues regarding copper powders rather than aluminum and discovered better warm conductivity with particles.

2.4 Study on the natural fiber based polymer composites

Lately, the enthusiasm of researchers and designers has turned over on using plant strands as viably and monetarily as could be allowed to deliver great quality fiber-strengthened polymer composites for basic, building, and different needs. It is a result of the high accessibility and has prompted the improvement of option materials rather than traditional or man-made ones. Numerous sorts of characteristic filaments have been explored for their utilization in polymer, for example, wood fiber [33], sisal [34], pineapple [35], jute [36] and banana [37].

Bax and Mussing [38] researched the mechanical properties of PLA strengthened with cordenka rayon strands, individually. A poor grip was watched utilizing Scanning Electron Microscopy examination. The most noteworthy effect quality and rigidity were found for cordenka strengthened PLA at fiber extent of 30 %. Waikamboo and Ansell [39] assessed the physio-mechanical properties of the normal fiber filler composites to evaluate their serviceability. Treated filaments with most astounding quality were utilized as fortification for cashew nutshell fluid grid and decided ductile properties, porosity furthermore analysed break surface geography of the composites. The goal was to expand the measure of ease regular assets in the composite. They presumed that the vicinity of lignin in the untreated hemp fiber offers extra cross connecting destinations and the untreated fiber surface is more perfect with CNSL (Cashew Nut Shell Liquid pitch) than antacid surface. Producing these synthetic or man-made materials posing a significant harm on the environment by releasing harmful gases such as CO2 into the atmosphere compared to the naturally made panels [40]. These synthetic nature of fiber also not easy to dispose which also create harm to the atmosphere. Continuation of their utilization is in this manner against the push to understand a "green" surroundings. In this way discovering option green materials which have equivalent capacity as stable safeguards, as well as bio-degradable, manageable, plenitude and in addition less wellbeing danger are of hobby. A few research are being completed concerning the capacity of normal fiber to be utilized as solid safeguard. Koizumi et al. [41] explored the sound

Characteristics of bamboo fiber, which was found nearly equal to sound absorption of glass wool.

Yang et al. [42] worked on rice straw-wood particle board to replace wood. An evaluation was done on the basis of industrial-made plywood which was further analysed. It is revealed that the wood particle of rice straw having lower specific gravity which provides enhanced sound absorption within the range of 1- 8 kHz as compared to both plywood board as well as fiber board.

Alessandro and Pispola [42] worked on kenaf fiber in echo hall, the outcomes were comparable with old synthetic sound absorbers. The results are not up to the mark but if the consequences on environment is taken into account then it is comparably good.

Saadatnia et al. [43] performed a test on acoustic pannel made up of wheat and barley straws. Ersoy and Kucuk [44] have exposed the usability of waste of industry made tea-leaf as an acoustic material. It has also revealed that by covering the back with woven cotton cloth layer, the acoustic properties of tea-leaf-fiber enhanced. 10 mm thick sound absorbing material made of tea-leaf-fiber is found to be equivalent to the traditional sound absorbers that is polyester. Unused ramie fiber when treated with alkalization can also yield capable result with the average absorption coefficient of 0.6 at frequency range between 3.15 KHz - 3.2 kHz [45]. Numerous work has been done on coir fiber and investigated the effect of pierced surface, several-layer procedure and compression on acoustic performance. Numerical method was applied to backing the date get from experiment. In conclusion it has been found that coir fiber is certainly excellent acoustic absorber at medium to high frequency at 1.5 - 5 kHz [46-47]. Research were done on the acoustic properties of arenga pinnata fibers extracted from a palm sugar tree [48, 49]. Having a width of 40 mm, it gives decent absorption coefficient of 0.75 - 0.88 at frequency between 2-5 kHz [50].

Abdullah et al. [51] worked on the paddy fillers. Within the range of frequency of 2 - 3.5 kHz gives absorption coefficient of 0.6 - 0.9, Good sound absorption performance is found.

Fatima and Mohanty [52] did the experiments and revealed the sound absorption of jute fiber. When jute fibre is used untreated it shows better acoustic characteristics compared to that with treatment at frequency 1 - 4 kHz. Unchanged straw and reed have also been examined for their acoustic properties. This thesis reports the power of well-known natural fibre which is sugarcane fiber known also known as “bagasse fiber” as an alternative acoustic material.

2.5. Effective Thermal Conductivity Models

Numerous methods have been proposed to developed models and correlation for calculating effective thermal conductivity for two phased material and composites. The first ever model which was used is Maxwell-Garnett model or M-G model (Maxwell, 1873) to calculate the effective thermal conductivity of two phase component. Inclusive reviews of articles have deliberated the applic ability of many of these models [53, 54]. For a two-phase material or composite, the easiest way is to arrange the materials in either parallel or series with respect to the direction of flow of heat, which gives the upper or lower limits of effective thermal conductivity.

For the parallel conduction model:

$$K_{eff} = (1-\phi_f)K_p + \phi_f K_f \tag{2.1}$$

Where k_{eff}, k_p, k_f are the thermal conductivities of the composite, the matrix (epoxy) and the filler (bagasse fibre) respectively and ϕ is the volume fraction of filler.

For the series conduction model-

$$\frac{1}{K_{eff}} = \frac{(1-\phi_f)}{K_p} + \frac{\phi_f}{K_f} \tag{2.2}$$

The above two equations (2.1, 2.2) are derived on the basis of the Rule of Mixture (ROM). Taso [55] resulting an equation which relates the thermal conductivity of a two phase solid mixture to the thermal conductivity of the single component. By supposing a parabolic distribution of the dis-continuous phase in the constant phase, Cheng and Vachon [56] acquired a solution to Tsao's model which did not need information of additional factors. Agari and Uno [57] recommend a different model for polymers which includes parallel as well as series conduction mechanisms. In accordance to this model, following equations governs the thermal conductivity of the composite is-

$$\log k_c = \phi C_2 \log k_f + (1-\phi)\log(c_1 k_m) \qquad (2.3)$$

Where, C_1, C_2 are experimentally determined constants of order unity. C_1 is a measure of the effect of the particles on the secondary structure of polymer, like crystallinity and the crystal size of the polymer. C_2 is the conductive chain formation potentiality of the particles. Bruggeman [58] derived an equation employing different assumptions for permeability and field strength for dilute suspension of spheres for a homogeneous medium and the implicit equation is given as:

$$1-\phi_f = \frac{K_{eff}-K_f}{K_p-K_f}\left(\frac{K_p}{K_{eff}}\right)^{1/3} \qquad (2.4)$$

Kanari model [59] which is a revised Bruggmen's equation is another empirical model using inorganic particles as filler. It presents a relationship between the thermal conductivity of composites and the volume fractions of filler which depends on the shape of the filler.

$$1-V_f = \frac{k_c - k_f}{k_m - k_f}\left(\frac{k_m}{k_c}\right)^{\frac{1}{(1+x)}} \tag{2.5}$$

Where V_f is the volume fraction of filler, *kc* is the thermal conductivity of composite; k_f is the thermal conductivity of the filler; *km* is the thermal conductivity of the matrix; and *x* is the constant determined by sphericity of the filler and *kf/km* , or only by the sphericity of the filler.

Lewis and Nielsen [60] derived a semi-theoretical model by modification of the Halpin-Tsai equation for a two phase system which assumes an isotropic particulate reinforcement and also takes into consideration the shape of particle as well as its orientation.

$$K_{eff} = K_p\left(\frac{1+AB\phi}{1-B\phi\psi}\right) \tag{2.6}$$

$$B = \left[\frac{K_f/K_m - 1}{K_f/K_m + A}\right] \qquad \psi = \left(\frac{1-\phi_m}{\phi_m{}^2}\right)\phi$$

Where, *kf* is thermal conductivity of filler material and 'ϕ' is the volume fraction of filler material. The value of A and *m* for different shapes are provided in the Table 2.1 and 2.2 respectively.

Table 2.1 Value of A for various systems

Type of dispersed phase	**Direction of heat flow**	**A**
Cubes	Any	2
Spheres	Any	1.5
Aggregates of spheres	Any	$(2.5/\phi_p)^{-1}$
Randomly oriented rods Aspect ratio=2	Any	1.58
Randomly oriented rods Aspect ratio=4	Any	2.08
Randomly oriented rods Aspect ratio=6	Any	2.8
Randomly oriented rods Aspect ratio=10	Any	4.93
Randomly oriented rods Aspect ratio=15	Any	8.38
Uniaxially oriented fibers	Parallel to fibers	2L/D
Uniaxially oriented fibers	Perpendicular to fibers	0.5

Table 2.2 Value of ϕ_p for various systems

Shape of particle	**Type of packing**	ϕ_p
Spheres	Hexagonal close	0.7405
Spheres	Face centred cubic	0.7405
Spheres	Body centred cubic	0.60
Spheres	Simple cubic	0.524
Spheres	Random close	0.637
Rods and fibres	Uniaxial hexagonal close	0.907
Rods and fibres	Uniaxial simple cubic	0.785
Rods and fibres	Uniaxial random	0.82
Rods and fibres	Three dimensional random	0.52

2.6 The knowledge gap

In the past few years, large amount of work have been done on particulates reinforced composites on the other hand, rare work has been carried out on fibre. Due to this there is a huge knowledge gap that needs a well-organized and methodical research in the zone of fiber reinforced polymer composites. A cumulative evaluation of the available literature tells that:

- Many of the studies are proposed at improving the heat conductivity of the polymer instead of improving its insulation capacity.
- Almost all known particulates and fibers have been already been used as a fillers content in the past, but there is very rare information available on using natural fibers like bagasse fiber, for improving the thermal insulation capability as well as sound absorption capability.
- On Sound absorption coefficient measuring instruments, very few have done the research work.
- Research on thermal conduction measuring device of natural fiber reinforced polymer composites are very uncommon.
- The relative knowledge of the effective thermal conductivity and acoustic absorption of a composite material and their interstitial properties such as volume fractions, density, and distribution of fibers, size of fibers, wettability and adhesive properties are not so complete.

2.7 Objective of the current Research

1. To develop a class of low cost thermally and acoustically insulated polymer composites using bagasse fiber reinforcement in epoxy resin.
2. To evaluate effective thermal conductivity experimentally and study the effect of fiber volume fraction.
3. To determine acoustical absorption coefficient experimentally and to study the role of fiber content.
4. To explore possible application areas for these newly developed composites.
5. Improving the thermal insulation properties of bagasse fiber reinforced epoxy composite
6. Measurement of effective thermal conductivity (K_{eff}) and sound absorption coefficient of bagasse fiber reinforced epoxy composite by varying the volume fraction of fiber experimentally.

Chapter Summary

This chapter includes--

- A complete analysis of research works on various characteristics of fibre filled polymer composites described by previous researchers.
- The knowledge break in previous researches.
- The objectives of the present work

The next chapter provide the knowledge on materials and methodology used for fabricating various natural fibre reinforced epoxy composites.

Chapter – 3

MATERIALS AND METHODS

Present chapter shows the effect on thermal conductivity and acoustic absorption coefficient of the bagasse fiber reinforced epoxy composite by varying the volume fraction of bagasse fiber filler content. It also defines the materials and methods used for the processing, fabrication and characterisation of the epoxy composites under this research. It presents the details of the characterization and thermal conductivity tests which the composite samples are subjected. The numerical methodology related to the determination of thermal conductivity based on finite element method is also presented in this chapter.

3.1 MATERIALS

3.1.1 Matrix material

As it is already has been discussed that mostly used matrix materials are metals, ceramics and polymers from which Polymer matrices known as the king of matrix family because of several reason as it is cost efficient, easy to fabricate intricate parts with low tooling cost and also have extra ordinary room temperature properties when compared to other matrices. Polymer matrices are of two kind i.e. thermoplastic or thermosetting plastics polymer. Thermoset matrices are permanent type of plastic whereas thermoplastic are temporary one. Due to large no. of molecular forms, thermoset resins provide excellent electrical as well as thermal insulation. Their wettability is far good having outstanding thermal stability and superior creep resistance. Generally used thermosetting resins are epoxy, polyester, vinyl ester and phenolic resin. Amongst all, epoxy resins are broadly used in fabricating many unconventional materials and composites because of their exceptional adhesion to a large variety of fibers, enhanced mechanical as well as electrical properties and also have excellent performance at higher temperatures. Additionally they have little shrinkage on curing and fair chemical resistivity.

In the present piece of work epoxy (LY 556) is chosen as the matrix material. It is a member of epoxide family. Its chemical name is Bisphenol-A-Diglycidyl-Ether (usually abbreviated to DGEBA or BADGE) and its molecular chain structure is shown in Figure 5. When it is combined with the hardener tri-ethylene-tetramine (TETA) which is an aliphatic primary amine with commercial designation, results in solvent free a room temperature curing system. HY 951 (Figure 6). The LY 556 epoxy resin and the hardener HY-951 are acquired from Ciba Geigy India Ltd.

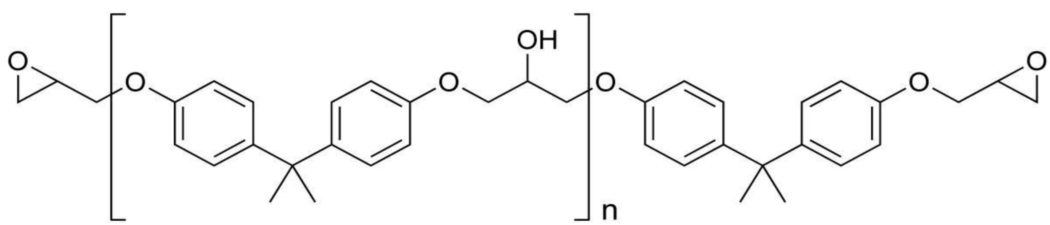

Fig. 3.1 Unmodified epoxy resin chain (‘n’ denotes number of polymerized unit)

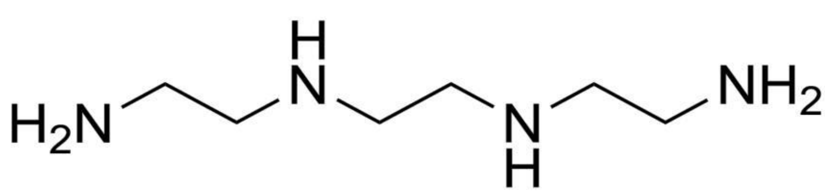

Fig. 3.2 Tri-ethylene-tetramine (hardener used for epoxy matrix)

Table 3.1 Important properties of epoxy resin

Characteristic Property	Inferences
Density (gm/cc)	1.1
Compressive strength (MPa)	90
Tensile strength (MPa)	58
Thermal conductivity (W/m-K)	0.363
Glass transition temperature (°C)	104
Coefficient of Thermal expansion (ppm /°C)	62.83
Electrical conductivity (S/cm)	0.105×10^{-16}

Fig. 3.3 Epoxy resin and hardener

3.1.2 Filler material (bagasse fiber)

Sugarcane is majorly grown in countries such as Brazil, India, Pakistan, Malaysia and Indonesia which are reside on an equator. On an average, a 10^4 m^2 area of sugarcane produces about 10^4 kg of sugarcane waste, which is also known as “bagasse”. The sugarcane fiber (waste) contained of minute and soft fibers which care supposed to be a good sound absorber. These bagasse fibers might hold the strength problem, which can be recovered by coupling with another stronger material. Bagasse consists of short and uneven fibrous strands remaining that produced after crushing the stalks of sugarcane. It mainly consists of maximum moisture, fibers and slight amounts of soluble solids. Percentage of involvement of each of these given constituents changes according to the variation, maturity, technique of harvesting and the efficiency of the crusher. Bagasse is primarily used a combustion raw material in the sugar cane mill furnaces. The low calorific value of bagasse results in low efficiency procedure. Which is the main problem encountered by the mill management system. Below tables showing the various properties of bagasse which makes its possible application in making composites.

Table 3.2 Chemical analysis of bagasse

Properties	Content (%)
Cellulose	45-55
Hemicellulose	20-25
Lignin	18-24
Ash	1-4
Waxes	<1

Table 3.3 Bagasse composition

Items	Content (%)
Moisture	49
Soluble solid	2.3
Fiber	48.7

Table 3.4 Mechanical properties of bagasse fiber

Properties	Values
Density (gm/cc)	0.07
Thermal conductivity (W/mK)	0.05

Fig.3.4 short fibres of bagasse

3.2 EXPERMENT DETAILS

3.2.1 Composite Fabrication

The fabrication from bagasse fibres into a round composite sample is divided into two stages, which are further used for measuring the thermal conductivity and sound absorption coefficient. 1^{st} stage is the pre-treatment stage and 2^{nd} is Fabrication stage. In the 1st stage, bagasse was cut into 1-2 mm length. Then it was dried under sun for approx. 1 week and further heated in the furnace at 80 ^{o}C for at least 5 minutes, so that the excess moisture in the fibre gets evaporated. In the preparation stage, the fibres are mixed in 4 different volume fraction with the epoxy resin mixed with hardener. The Polymer matrix (epoxy) composite mixed with bagasse and then 4 samples are fabricated by simple hand lay-up technique. Epoxy (LY 556) resin cured at the Low temperature is taken as a matrix material which is then mixed with the hardener (HY951). These both must be mixed in the ratio of 10:1 by weight as permitted. The mixture (epoxy filled with fibers) is then gently emptied into the cylindrical glass to acquire the composite sample having disc shape. Then finally the semi liquid castings are kept at room temperature for about 25 hours to go through complete polymerization, at last the glass molds are broken to get the samples for further testing of sample to get sound absorption coefficient and effective thermal conductivity. 4 samples are prepared according the above procedure with different fibre volume fraction.

Fig. 3.5 Bag**asse** fibre reinforced epoxy composite fabrication by hand lay-up technique

Table 3.5 Samples prepared in 4 different volume fraction

composition
Epoxy + 0 vol% bagasse
Epoxy + 13 vol% bagasse
Epoxy + 27 vol% bagasse
Epoxy + 40 vol% bagasse
Epoxy + 54 vol% bagasse
Epoxy + 65 vol% bagasse

Fig.3.6 Prepared sample in different volume fraction

3.2.2 Thermal Characterization: Experimental Determination

Also known as Guarded Heat Flow Meter Thermal Conductivity Measurement System from Nortest. Unitherm TM Model 2022 is a thermal conductivity measuring device which is used to measure the effective thermal conductivity of various kind of materials such as polymer, glass, ceramic, rubber, composites and other materials of having medium or low thermal conductivity. In the present research work, the effective thermal conductivity of the composite sample is measured at room temperature with the help of this instrument. Round disc shaped specimens dimension of about diameter = 50 mm, thickness = 3 mm are used for calculations. The experiment is conducted on the basis of **ASTM E-1530** standards. Unitherm TM Model 2022 tester is given in Figure 3.5.

Operating Principle of Unitherm TM Model 2022

The material is apprehended under uniform compressive load between two shining surfaces, each measured at different temperatures. Heat flow transducer is calibrated in lower surface. From the upper plate at high temperature heat flows through the sample, towards the lower plate, creating an axial temperature gradient in the pile. After attainment of thermal equilibrium, the temperature gradient across the sample is measured with the output received from the heat flow transducer. Measured values of temperature difference T and the sample thickness x are used to calculate the thermal conductivity of the composite sample. The temperature trickle through the specimen is measured with temperature sensors in the exceedingly conductive metal surface layers on either side of the example.

By definition "thermal conductivity is the trading of vitality between contiguous atoms and electrons in a directing medium, it is a material property that depicts heat stream inside of a body for a given temperature distinction for each unit zone. “For one-dimension heat flow, the equation is given as:

$$Q = KA\frac{T_1 - T_2}{X}$$

Where, Q is the heat flux (Watt), K is the thermal conductivity (W/m K), A is the cross-sectional area (m^2), ($T_1 - T_2$) is the difference in temperature (K), x is the thickness of the sample (m). The thermal resistance of a sample can be given as

$$R = \frac{T_1 - T_2}{Q/A}$$

Where, R is resistance of the sample between hot and cold surfaces (m^2 K/W). We can get that

$$K = \frac{X}{R}$$

In Unitherm™ 2022, the transducer part of lower plate measures the ‘Q’ which is heat flux and the temperature difference between the upper surface and lower surface. Accordingly the thermal resistance is easily evaluated between the surfaces. Using the value of thickness and cross-sectional area, the effective thermal conductivity of the samples can be easily evaluated by using above equation.

Figure 3.7 Thermal conductivity testerUnithermTM2022

3.2.3 Measurement of sound absorption coefficient

The measurement of sound absorption coefficient (denoted as α) was performed in an impedance tube by applying two microphone transfer function method according to ISO 10534-2:2001. The acoustic microphone used are the 1/2inch pre-polarised free-field microphone (GRAS 40AE) with ½ inch CCP pre-amplifier (GRAS 26CA). RT Pro Photon v6.34 analyser with Dactron software was used as the data acquisition system. The signal processing of the measured data was done using Mat lab. With diameter of the tube i.e. 33 mm, the reliable frequency range for this experiment is between 500 Hz to 4 kHz. Below figure shows the measurement setup for the test. The sample was placed at the end of the impedance tube and backed by a rigid surface. The loudspeaker feeds the white noise signal in the tube where the incident and reflected sound pressure recorded by the microphones are then processed to have the absorption coefficient of the sample.

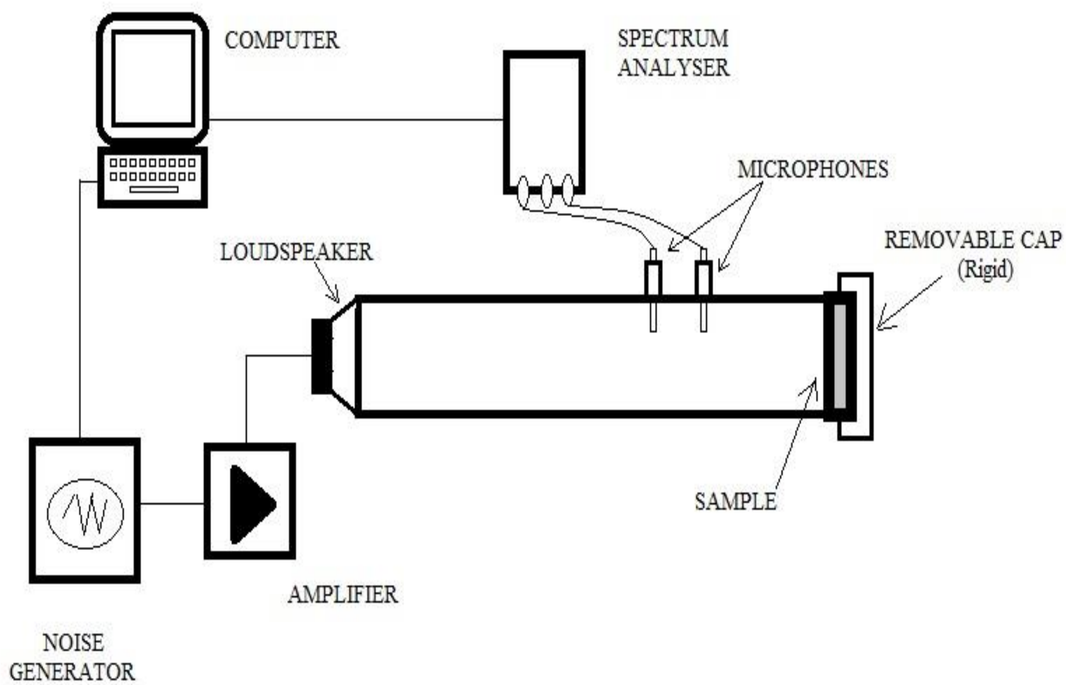

Fig.3.8 Measurement setup for the sound absorption test

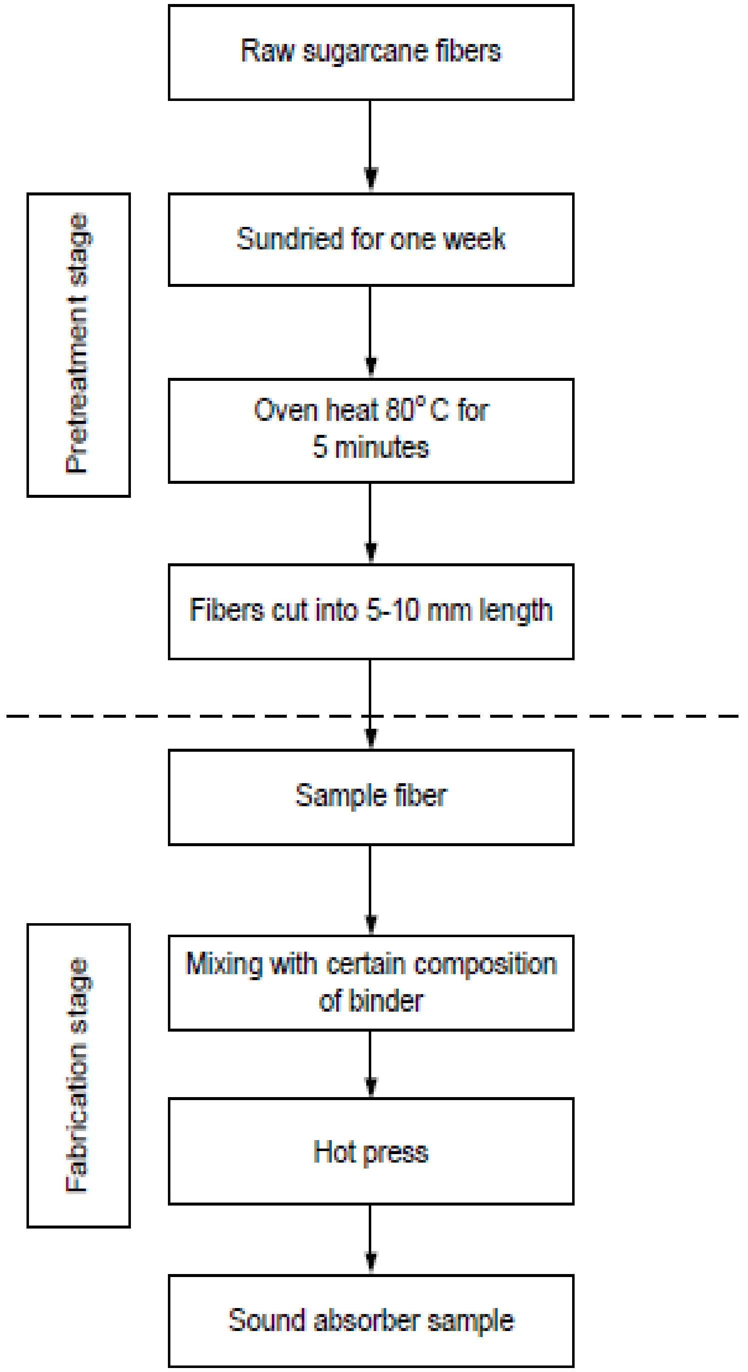

Fig.3.9 Flow chart of absorber sample construction process

Fig.3.10 Prepared sample in different volume fraction

Chapter Summary

This chapter concluded:

- The explanation of materials (matrix and fillers) and methodology used in this study.
- The detailed fabrication process and characterization of the composites.
- The details of effective thermal conductivity measurement.
- The details of sound absorption coefficient measurement.

The next chapter presents the test results related to calculation of thermal conductivity and absorption coefficient of the bagasse fiber epoxy composites.

Chapter - 4

RESULTS AND DISCUSSION

4.1 THERMAL CHARACTERZATION

Effective thermal conductivity is calculated by the above provided equations for different volume fractions at 0%, 13%, 27%, 40%, 54% and 65% of bagasse fibres content. It has been found that the incorporation of bagasse fiber results in reduction of thermal conductivity of epoxy resin and thereby improves its thermal insulation capability. Which can be further used in making thermal insulators. With the addition of 13%, 27%, 40%, 54% and 65% of filler content, the thermal conductivity is reduced by about 30 %, 47.1%, 66.1%, 73.2%, 77.4%, respectively. And with the addition of 65% of filler content which is maximum the thermal conductivity drops by about 77.4% in neat epoxy is achieved. Table 4.1 and figure 4.1 shows the variation of thermal conductivity with bagasse fiber volume fraction.

TABLE 4.1 Variation of thermal conductivity with fibre volume fraction

SAMPLE	VOLUME FRACTION (%)	K_{eff} (W/mK)
1	0	0.363
2	13	0.254
3	27	0.192
4	40	0.123
5	54	0.097
6	65	0.082

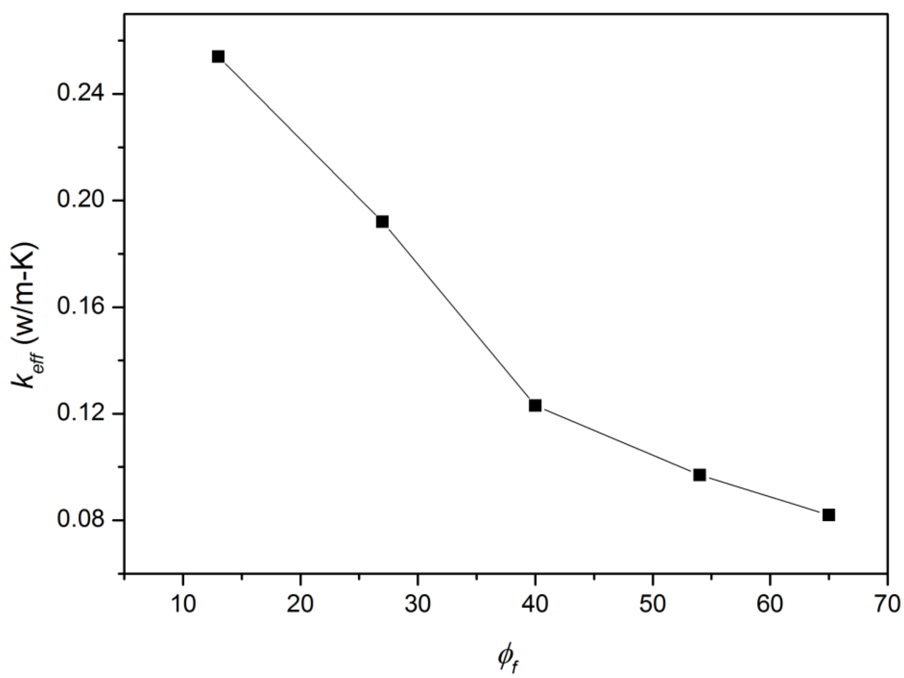

Fig. 4.1. Variation of thermal conductivity with fiber volume fraction

4.2 ACOUSTIC CHARACTERIZATION

Figure 4.2 and table 4.2 plot the acoustic absorption coefficient of bagasse fibre reinforced epoxy composite and it has been shown that with the increase in fibre volume fraction, the sound absorption coefficient increases. The results shows that at 13% filler volume fraction below 3 KHz it does not significantly affect the performance of sound absorption. Good sound absorption shows (α>0.5) above 3 KHz at 0.57. For 65% fibre content. Sound absorption showing good results between 2 KHz- 4 KHz of 0.502 – 0.722. Good sound absorption is found at 2 KHz – 4 KHz with average absorption coefficient of 0.64 and is comparable against that from the classical synthetic absorber. Below table and graph showing the variation of absorption coefficient for 13%, 27%, 40%, 54% and 65% volume fraction of bagasse fibre at 8 different frequencies i.e. 500, 1000, 1500, 2000, 2500, 3000, 3500 and 4000 Hz. For 13% filler volume fraction average absorption coefficient is 0.33. Similarly at 27%, 40%, 54% and 65% volume fraction of bagasse fibre average absorption coefficient are 0.38, 0.46, 0.49 and 0.52 respectively.

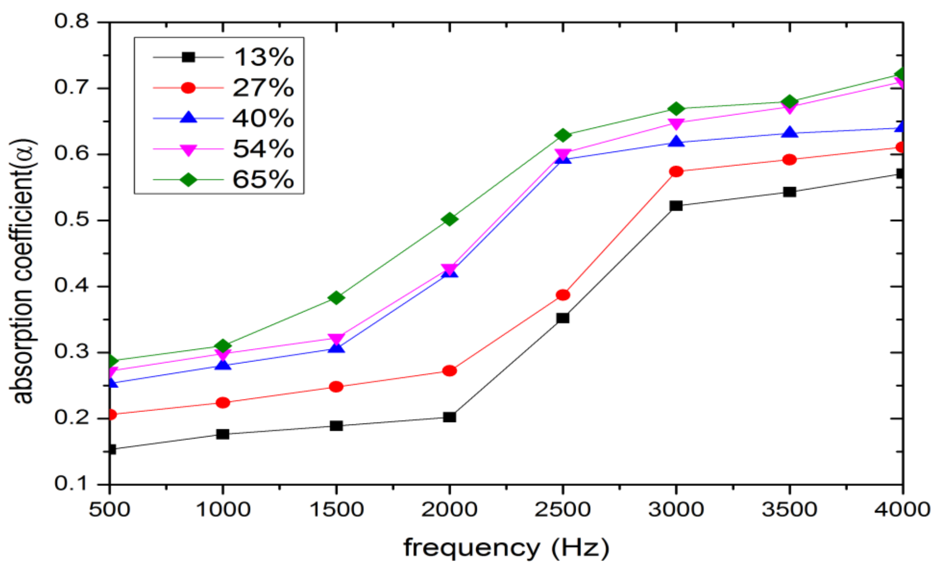

Fig.4.2 Variation of absorption coefficient with filler content at different frequency

Table 4.2 Variation of absorption coefficient with filler content at different frequency

Volume fraction (%) (Hz)→	Absorption coefficient (α)							
	500 (Hz)	1000 (Hz)	1500 (Hz)	2000 (Hz)	2500 (Hz)	3000 (Hz)	3500 (Hz)	4000 (Hz)
13	0.153	0.176	0.189	0.202	0.352	0.522	0.543	0.571
27	0.206	0.224	0.248	0.272	0.387	0.574	0.592	0.611
40	0.253	0.280	0.306	0.420	0.592	0.618	0.632	0.640
54	0.272	0.298	0.322	0.428	0.602	0.648	0.672	0.710
65	0.287	0.310	0.383	0.502	0.629	0.669	0.680	0.722

Chapter - 5

CONCLUSION

- Successful fabrication of bagasse fiber reinforced epoxy composites is possible by simple hand layup technique.
- With addition of bagasse fibre, heat conduction capability is notably decreased.
- With addition of bagasse fibre, acoustic absorption coefficient is notably increased.
- It is found that the results obtained with the addition of 13%, 27%, 40%, 54% and 65% the thermal conductivity decreased 30%, 47.1%, 66.1%, 73.2% and 77.4% respectively.
- It is found that the results obtained with the addition of 13%, 27%, 40%, 54% and 65%. Good sound absorption is found at 2 KHz – 4 KHz with average absorption coefficient of 0.64 and is comparable against that from the classical synthetic absorber.

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